Effects of Multiple Stressors on Eelgrass Restoration Projects

Ronald M. Thom, Amy B. Borde, Gregory D. Williams, John A. Southard, Susan L. Blanto *and* ***Dana L. Woodruff***
Battelle Marine Sciences Laboratory
Pacific Northwest National Laboratory

Introduction

The purpose of this paper is to review existing information on eelgrass restoration and potential effects of multiple stressors on the success of eelgrass restoration projects in Puget Sound. Although an earlier review found that less than 60% of the eelgrass restoration projects on the West Coast were successful, it was concluded that by careful site selection and planting, eelgrass could be restored (Thom 1990). A recent, comprehensive, nation-wide review of seagrass restoration efforts by the National Marine Fisheries Service (Fonseca and others 1998) and ongoing tracking of eelgrass mitigation projects in California (Hoffman 2000; Merkel & Associates, Inc. 1998) verify these findings. Projects we have conducted in Puget Sound and other northwest estuaries have had variable success. Through our research conducted at restoration sites and through several eelgrass ecology projects, we have learned that eelgrass restoration remains difficult but possible.

To improve the probability of eelgrass restoration success, we have conducted a series of experiments to further refine the growth requirements of eelgrass. In these experiments, we have made observations and gathered data at transplant and eelgrass research sites that have helped us better understand the multitude of factors that can affect the success of an eelgrass restoration project. Two of our key findings are that eelgrass performance goals may be unrealistic and that random natural and human-induced stressors can play a major role in affecting the success of restoration projects.

We present here some of our information along with a summary of the latest reviews. We also describe some of our findings relative to factors affecting the success of eelgrass restoration in the Pacific Northwest.

Physical and Chemical Requirements of Eelgrass

For eelgrass to exist at a site, the site must meet eelgrass growth and maintenance requirements. Knowing the growth requirement greatly assists in understanding why a project may or may not meet performance objectives. Studies conducted in Puget Sound, the outer coast estuaries in Washington and Oregon, and in California have refined the data on conditions that support eelgrass growth. In general, eelgrass grows extensively in soft sediment in shallow areas of estuaries. Particularly in central California northward, eelgrass flourishes in areas where water circulation maintains cooler water temperatures and supplies nutrients to the plants. The primary factors controlling eelgrass growth are

- Light availability
- Substrata composition
- Temperature
- Salinity
- Inorganic nutrient availability
- Wave/current energy

Light

Through its role in photosynthesis, light affects the depth distribution of eelgrass. The degree to which light is attenuated (lost) with depth in the water column is a strong determiner of the lower limit to which eelgrass can grow. Figure 1 shows the depth distribution of eelgrass in Puget Sound, Willapa Bay, and Coos Bay. As evidenced by a smaller attenuation coefficient (Kd), light penetrates much deeper in central Puget Sound as compared with either of the other estuaries. Thom and others (1998) found that below approximately -1 m relative to mean lower low water (MLLW), eelgrass density declined in Puget Sound in concordance with reduced light penetration. Eelgrass in San Francisco Bay is low-light adapted (Zimmerman and others 1991), as evidenced by the very low photosynthetically active radiation (PAR) levels of 35 µM m^{-2} s^{-1} required to maintain a positive carbon balance. Using this information, Zimmerman et al. calculated the hours of light at saturating levels required to maintain a positive carbon balance in eelgrass at sites that varied in water clarity (Table 1).

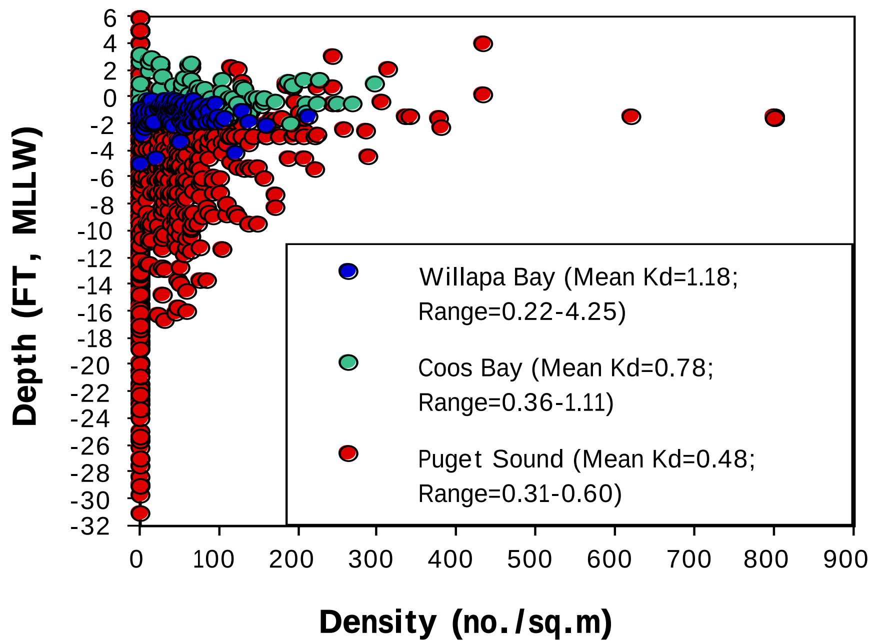

Figure 1 Eelgrass density vs. depth at Willapa Bay, Coos Bay and Puget Sound.

Table 1. Diffuse Attenuation Coefficients (DAC) and Number of Hours per Day of Photosynthesis-saturation PAR (H_{sat}) Needed to Maintain Positive Carbon Balance in Eelgrass for Sites in San Francisco Bay where Eelgrass is Abundant (from Zimmerman and others 1991)

Site	Mean DAC (m^{-1})	H_{sat} (hrs d^{-1})
Paradise Cove	3.1	11.1
Pt. Molate	22.2	10.2
Chevron Pier	1.9	8.4
Keil Cove	1.6	6.7
Richmond Harbor	1.5	7.8

Our data on light requirements for eelgrass in Puget Sound indicate that photosynthesis is saturated at about 300 µM m^{-2} s^{-1}, which must be maintained for at least 3 hours during the spring and summer for eelgrass to build up carbohydrate reserves to allow it to survive through the winter.

Substrata

Eelgrass can grow in a wide variety of substrata (Figure 2). The plants flourish in medium to fine sands that contain relatively high levels of organic matter and nutrients. The organic matter supports eelgrass through development of a nutrient-rich rhizosphere.

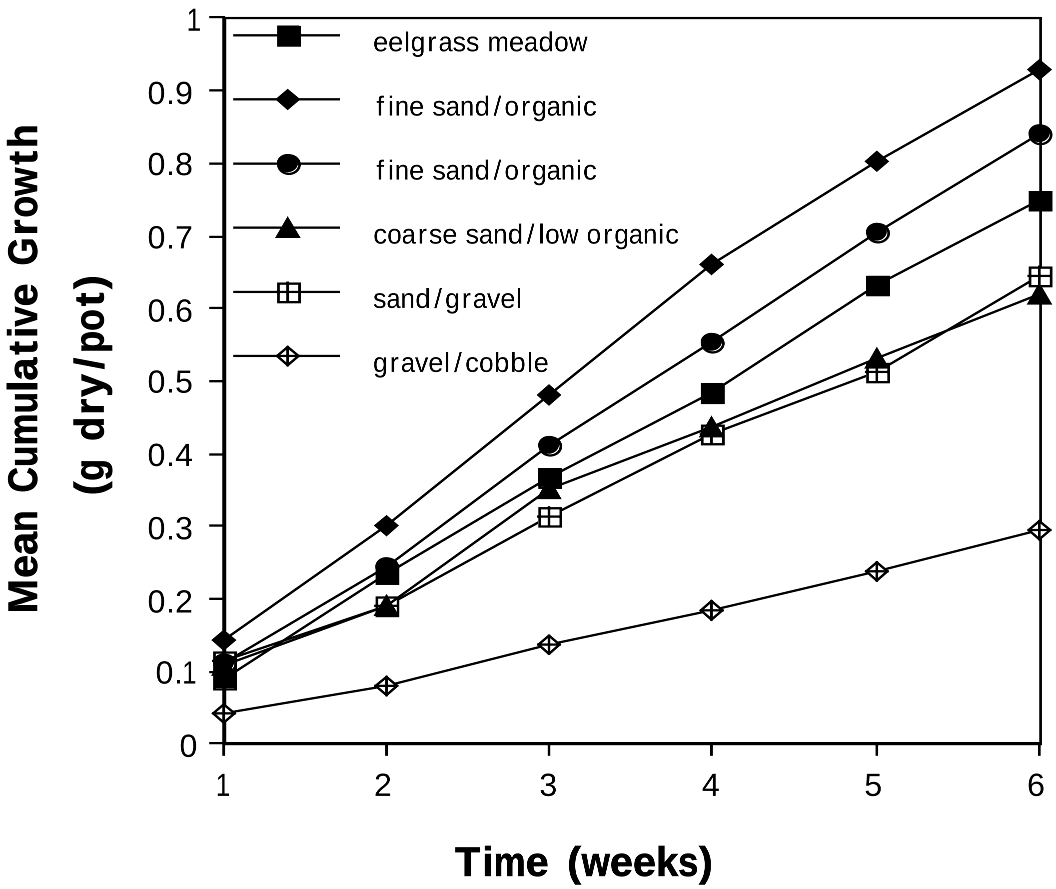

Figure 2 Growth of eelgrass leaves in various substrata types. Experiments were conducted in a flowing seawater system at the Battelle Marine Sciences Laboratory.

Temperature

Temperature affects metabolic rates in eelgrass and if too high, can increase plant respiration enough to kill the plant. Maintaining circulation of deep, cooler, nutrient-rich water helps control temperature increases that might be associated with a restoration project. Our research has shown that the optimal temperature range for eelgrass is between 7 and 12^{o}C, based on positive carbon balance experiments.

Salinity

Salinity affects eelgrass productivity. Our studies indicate that eelgrass maintains a high photosynthetic activity at 20-35 ppt salinity (Thom unpublished data).

Nutrients

Nutrient requirements have not been investigated adequately for eelgrass along the West Coast. We do know that shallow-water nutrient limitation occurs over extended periods of time even in cool nutrient-rich systems such as Puget Sound (Thom and Albright 1990). There is a growing awareness that eutrophication may play a major role in producing macroalgal blooms that have significant negative impacts on eelgrass

(Thom and others 1998; Frankenstein 2000). Concerns focus on the increasing fragmentation of eelgrass beds due to macroalgal smothering of eelgrass. This concern is global in nature (Short and Echeverria 2000).

Wave/Current Energy

Some water motion is needed to supply nutrients to the plants, cool the flats, and prevent the buildup of floating organic matter that can smother eelgrass. Strong waves and currents will erode the sediment in an eelgrass bed (Phillips 1984). Our studies indicate that eelgrass patches can withstand burst velocities up to about 80 cm s^{-1} before they begin to erode (Hart Crowser and others 1997)

Stochastic Factors

The role of natural events such as El Niños, major storms, winter freezes, etc., is essentially investigated along the West Coast relative to eelgrass. We have noted losses of eelgrass following winter freeze events (unpublished data). Decadal-scale shifts in water temperature and strongly coupled forcing factors may be very important in controlling eelgrass abundance. However, we have no long-term focused investigations.

Eelgrass Restoration in California

Robert Hoffman of the National Marine Fisheries Service (NMFS) tracks eelgrass transplant projects in California (Table 2). The database contains a list of 39 projects completed (i.e., constructed) between 1976 and 1998 and two that were scheduled for completion in 1999. The projects range in size from <0.1 ha to 4.8 ha. The projects are judged successful if there is a net increase in eelgrass coverage. Based on this criterion, 14 (36%) of the projects were considered successful; 5 (13%) were partially successful; 7 (18%) were not successful; and 13 (33%) were pending the results of monitoring studies. Most projects (61%) are smaller than 0.1ha in size. Average project size has increased through time, as has the percentage of projects rated successful. Of the eight projects larger than 1.0 ha, three have been successful, one was partially successful, and four are pending.

Table 2. Summary of Eelgrass Projects in California from Robert Hoffman (2000). (Projects listed as <0.1 ha were included in averaging as 0.05 ha.)

Year	No. Projects	Mean Size (ha)	Max. Size (ha)	Success (%)
1976-79	4	0.4	1.6	25
1980-84	3	0.6	1.7	33
1985-89	12	0.6	3.8	58
1990-94	9	0.3	2.0	56
1995-98	11	1.0	4.8	all pending
1999	2	2.0	4.0	planned

Guidelines for Conservation and Restoration of Seagrasses

Fonseca and others (1998) developed a comprehensive assessment and set of guidelines on seagrass restoration based on an extensive literature review, discussions with seagrass restoration experts throughout the country, and directed research over 18 years at the NMFS Laboratory in Beaufort, North Carolina. The authors state that seagrass planting is no longer experimental; however, the following should be taken into consideration:

- Planning, planting, and monitoring require attention to detail and should not be oversimplified.
- The success rate of permit-linked seagrass mitigation projects remains low, but appears to result from failures in the planning process as much as from any other cause.
- Improvements are needed in site selection, care in planting, and incorporation of plant demography.
- Seagrass plantings that persist and generate target acreages have been shown to quickly provide many of the functional attributes of natural beds.

Eelgrass and Shallow—Water Habitat Restoration along Pacific Coast

Merkel & Associates, Inc. (1998) summarized information from 47 eelgrass and shallow-water habitat restoration projects spanning from San Diego to Vancouver, B.C. Many of these were also included in the list compiled by Hoffman on California projects. Success of the eelgrass projects ranged from less than 10% to 100% annually, with success improving through time. Focused mitigation and enhancement projects have resulted in a cumulative increase in eelgrass area along the Pacific Coast since 1985. Prior to that, eelgrass was being lost through poor eelgrass transplanting success.

The authors found that site manipulations had an effect on eelgrass transplant success rate. Projects involving fill, excavations, or with protection from waves had success rates greater than 90%. In comparison, the success rate on unmanipulated sites was approximately 38%.

Nineteen of the eelgrass projects included the creation of shallow-water habitat as a supporting element for eelgrass. Only two projects reviewed had as their principal objective the creation of shallow-water habitat: Port of Los Angeles Pier 300 shallow-water mitigation area and Port of Long Beach Pier J 300 shallow-water mitigation area. At the Port of Los Angeles, dredged material was used to fill a 190-acre deep area to a depth of –18 ft MLLW. In Long Beach, a 116-acre basin was created by excavation of upland. Both projects have been deemed successful by regulatory agencies. The Batiquitos Lagoon Enhancement Project also involved significant dredging and filling to create shallow-water habitat. Dredging was done to increase the tidal prism and improve circulation. Filling created bird-nesting islands at strategic locations in the Bay. This project has exhibited early success in terms of both shallow-water habitat functions as well as eelgrass colonization.

Functional Performance of Eelgrass and Shallow-Water Restoration and Enhancement Projects

The functional performance of an eelgrass restoration project is most often assessed by measuring the abundances of animals associated with the restored site. Rather than sampling all possible animals groups, groups of selected animal types (e.g., crabs, seagrass-associated fish, shorebirds) or species (e.g., light footed clapper rail, juvenile chinook salmon) are targeted. The vast majority of monitoring programs associated with restoration projects inadequately sample functional performance. In general, larger more costly projects, especially those conducted as mitigation, have a more robust monitoring program that includes functional performance documentation.

After reviewing seagrass restoration projects nationally, Fonseca and others (1998) concluded that seagrass plantings that persist and meet the size criteria quickly provide many of the functional attributes of natural beds. Our experience monitoring eelgrass restoration projects in Puget Sound has shown that macrofauna such as Dungeness crab and demersal fish occupy the planted areas almost immediately after planting (unpublished data). In addition, transplanted plots over 1-year old harbor prey of juvenile salmon in densities very near those found in reference meadows. Other functions, such as substrata stabilization, nutrient cycling, and enhancement of larval settlement and survival, need to be more fully studied to better understand the rates of development and dynamics of these functions.

Reports on the functional performance of shallow-water habitat restoration projects are rare. The best examples come from the Port of Los Angeles, Port of Long Beach, and the Columbia River estuary. New information from the Batiquitos Lagoon project also provides useful information (Merkel & Associates, Inc. 1998). The general conclusion from monitoring these areas is that they are providing habitat for a number of species of fish and invertebrates at levels at least as great as those provided by the areas in their prior condition. In Los Angeles, the shallow-water habitat is providing prey fish for the least tern colonies nearby. The Long Beach excavation project has been more heavily used by birds than was originally predicted, and also supports a nursery for several fish species. Batiquitos Lagoon is now an important habitat for a wide variety of fish and invertebrates, as well as the birds that prey on the fish. As an example of an unintended result, dredged material islands (not created as part of a mitigation or restoration effort) in the Columbia River estuary have provided new nesting habitat for tern colonies that prey on endangered juvenile salmon and other species migrating through the estuary.

Three Projects in Washington State

Three eelgrass restoration projects that we have been involved in represent a range of outcomes that provide useful information regarding future projects. The projects were conducted in Grays Harbor estuary, at Clinton ferry terminal (southeast Whidbey Island), and in Eagle Harbor (Bainbridge Island). We also have a learned a considerable amount through development of eelgrass cultures in large flowing seawater tanks (Borde and others 2001).

Grays Harbor Estuary

Transplants were conducted in small plots located within oyster shell piles on flats in the estuary. The transplants were monitored annually for 5 years through support by the Seattle District Corps of Engineers. The results showed that eelgrass density in five of the six plots developed rapidly over the first 2 to 4 years (Figure 3) and matched reference site densities after 2 to 3 years. The sixth plot (CSS2) developed for the first 2 years was lost due to burial in Year 3. Sedimentation and erosive processes on the flats changed the shaped of the plots from square to narrow and rectangular. The study showed that eelgrass could be planted in areas where moisture was maintained during periods of low tide. In fact, eelgrass leaf width increased with increasing depth of ponds formed at low tide. All plots, including controls, declined in the fifth year because of large shifts in sediment.

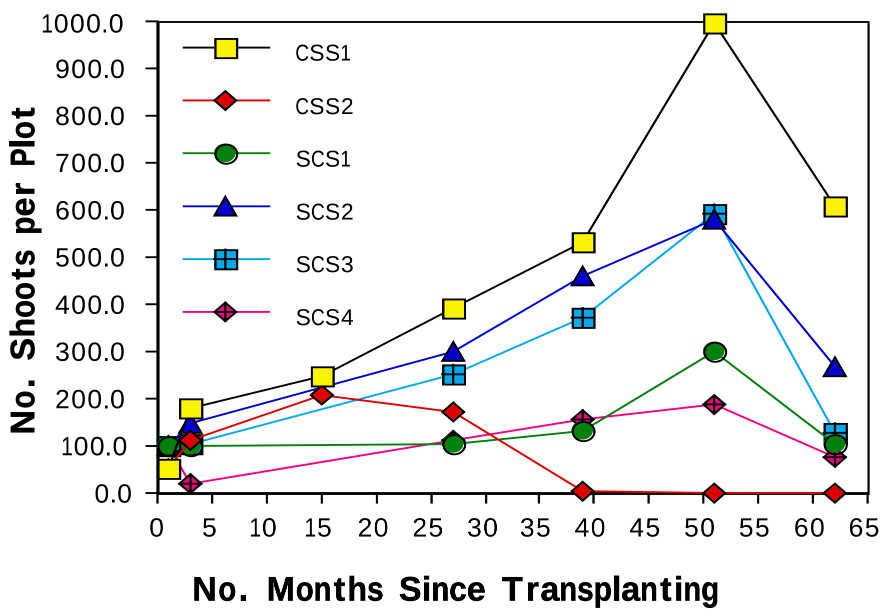

Figure 3 Development of eelgrass density in six plots in Grays Harbor estuary. The initial plantings were done in summer of 1990.

Clinton Ferry Terminal

Eelgrass was transplanted into unvegetated areas located within an existing eelgrass meadow near the terminal starting in 1997. The plots have shown general steady gains in eelgrass shoots through time (Figure 4). The changes in abundance in the transplanted plots have followed the annual variations in abundance in the reference plots. The transplanted plots appear to be sustaining eelgrass populations, although they have only reached about 35% of the abundance of the reference plots. It is important to note that there was an approximate 3.6-fold increase in total abundance in the reference plots between 1997 and 1998. We believe that newly planted plots are incapable of this degree of change in one year. This indicates that, because of potential large-scale annual variability in the reference plots, comparison of performance of transplanted plots with reference plots must be viewed with caution. We have noted immediate and longerterm disturbance of eelgrass transplants through burying and uprooting activities by Dungeness crab. Sunken logs and boat anchors have also resulted in loss of both planted and natural eelgrass at the site.

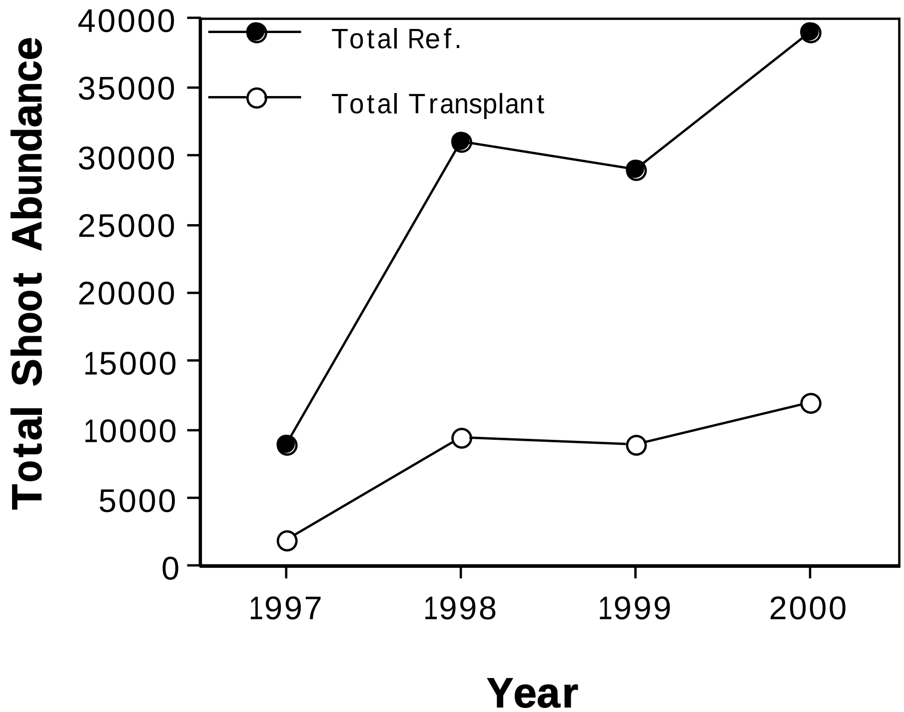

Figure 4 Changes in total shoot abundance within transplanted plots and reference plots. The abundances are calculated for equal areas of transplant and reference plots.

Eagle Harbor

A 1.5-ha site, located immediately east of the small city marina in Eagle Harbor, was planted in 1998 with 10,000 shoots of eelgrass. Because this site had only a few plants of eelgrass prior to planting, we conducted a site assessment in 1997, which included small transplant experiments. The site assessment indicated that the site was marginal for eelgrass, but transplants did survive over several months. During planting and especially the following year, the site was overwhelmed by massive piles of green seaweed (*Ulva* spp.) and some large brown seaweed (*Laminaria saccharina*). The eelgrass in the plot was smothered by the seaweed, and survival by the second year was minimal. These quantities of seaweed were not noted during the original site assessment. Seaweed blooms in noxious quantities were reported during these same years throughout Puget Sound (Frankenstein 2000). Boat anchors, chains, and boat groundings were also noted to have affected the survival of the plants in the plot.

Eelgrass Stockpile

Since 1997, we have maintained a stockpile of eelgrass that has given relevant results to eelgrass plantings. First, the large tanks are filled with rapidly flowing cold seawater collected from the mouth of Sequim Bay; a very well flushed location. The plants in the tank are under 1.0-1.5 m of water and therefore receive near the maximum available light during all seasons. There are no human-induced stressors on the plants. Borde and others (2001) report that the initial 5,500 plantings were reduced to about 1,500 within the first six months. The reasons included massive epiphyte loads as well as seaweed blooms and mussel sets on the leaves. Later in the first year, grazers established on the plants, which effectively controlled the algae and seastars foraged on mussels. The net result was that plant abundance increased to over 11,000 by the end of the first year. By the second year almost 30,000 plants were present, which likely exceeded the carrying capacity of the tanks over the long-term. In year three, shoot abundance declined to about 18,000, along with an increase in the size of the plants in the tanks. Plant canopy cover in the tanks reached 100% by year two and was maintained at that level even though there were declines in total abundance. The results from the stockpile revealed that eelgrass systems require many components of the ecosystem to be present for the eelgrass to flourish, including herbivores and predators. In addition, one can expect, even under ideal growth conditions, that there will be a loss of plants early in the project. Finally, use of plant cover in combination with shoot density may be the best indicator of eelgrass system development.

Lessons Learned

The previous projects provide a substantial basis from which to develop a set of lessons learned that can further improve eelgrass and shallow-water habitat restoration projects. A restoration project strives to achieve the following:

- A self-sustaining system.
- Resilience to disturbance.
- A structure similar to natural systems.
- Functional performance similar to natural systems.

We learned that it is possible to successfully create sustainable eelgrass and shallow-water habitats that meet these criteria. The long-term persistence and performance of these systems is not well studied, however. Some eelgrass projects have been in place for almost 15 years. Although it is reasonable to assume that these older systems are functioning like natural systems, we lack any comprehensive data to verify this point.

We also know that planted systems may take years to develop even under optimal conditions. Development of the system depends on processes such as herbivorous, carnivorous, and organic matter deposition, and these processes take time to establish. New systems, as well as natural systems, are susceptible to natural and human-induced disturbances that may not be active or apparent during site assessments. Certainly, the seaweed bloom and boat disturbances of the Eagle Harbor site were major contributors to the loss of eelgrass there. Although we expected boats to be a potential threat (and erected warning buoys to keep boats out of the plot), the seaweed bloom was not expected. Seaweed blooms are a sign of potentially worsening conditions in Puget Sound and threaten to damage planted as well as natural eelgrass meadows (Thom and others 1998).

Finally, the reference sites showed large fluctuations in either shoot density or abundance. These fluctuations indicate that transplanted eelgrass will also be subjected to natural variations forced by a multitude of factors, such as water clarity and temperature. If eelgrass abundances are too low, the patch may not be able to recover from these fluctuations. To create a sustainable population, there is a minimum viable population (MVP) size, which probably varies according to site conditions and potential natural and human-induced stressors.

To create eelgrass and shallow-water habitat in Puget Sound, the lessons learned are as follows:

- Protect the site from large wave disturbances.
- Create gently sloping areas.
- Maintain circulation to prevent anoxic conditions and promote cooler water temperatures.
- Plant eelgrass when rhizome energy reserves are greatest.
- Use nearby meadows as donor stock.
- Use nearby meadows as models for appropriate depth range.
- Conduct experimental planting to help determine areas suitable for full planting.
- Conduct a site investigation to assure that the site provides the required conditions for eelgrass to flourish.
- Use suitable substrata grain size for fill projects.
- Avoid stagnant areas with high inorganic nutrient loading.
- Avoid areas with persistent levels of contaminant loads.
- Avoid areas where physical disturbances are high.
- Avoid areas where sedimentation or erosion rates will be great enough to disturb eelgrass.

- Monitor sites using consistent and defensible protocols for both key structural and functional parameters (canopy cover may be best used in combination with density).
- Monitor most frequently during the first few years when chances of failure are greatest, then less often for 10-20 years.
- Develop an adaptive management program that allows for some adjustments if needed.

Acknowledgements

We sincerely appreciate the ongoing support and technical guidance of the Washington Department of Transportation (WSDOT), especially Jim Schafer and Tina Stotz, as well as Lauren Warner of the Seattle District Corps of Engineers in funding the research and monitoring that helps better plan nearshore restoration projects in Puget Sound. Personal communications with Sandy Wyllie Echeverria, Charles Simenstad, Annette Olson, Anne Shaffer, Ronald Phillips, Robert Hoffman, Tracey McKenzie, Mark Fonseca, and Keith Merkel are gratefully acknowledged. Blythe Barbo was instrumental in the production of this paper.

Literature Cited

Borde, A.B., R.M. Thom, and E.D. Fagergren. 2001. "Eelgrass in Captivity: Population Dynamics in a Confined System." PNWD-SA-5311. In *Proceedings of Puget Sound Research 2001. The Puget Sound/Georgia Basin Ecosystem: Status, Stressors, and the Road to Recovery*, February 12-14, 2001, Bellevue, Washington.

Fonseca, M.S., W.J. Kenworthy and G.W Thayer. 1998. Guidelines for the conservation and restoration of seagrasses in the Unites States and adjacent waters. NOAA Coast Ocean Program Decision Analysis Series No. 12. NOAA Coastal Ocean Office, Silver Spring, Maryland.

Frankenstein, G. 2000. Blooms of ulvoids in Puget Sound. Puget Sound Water Quality Action Team, Olympia, Washington.

Hart Crowser, Battelle, and Hartman Associates. 1997. Passenger-only ferry propeller wash study passenger-only ferry terminal Vashon Island, Washington. Report prepared for Washington State Department of Transportation, Olympia, Washington.

Hoffman, R. 2000. Unpublished summary of eelgrass (*Zostera marina*) transplant projects in California (1976-1999). National Marine Fisheries Service.

Merkel & Associates, Inc. 1998. Analysis of eelgrass and shallow water habitat restoration programs along the North America Pacific Coast: lessons learned and applicability to Oakland Middle Harbor enhancement area design. Report prepared for Middle Harbor Enhancement Area Technical Advisory Committee. Merkel & Associates, Inc., San Diego, California.

Phillips, R.C. 1984. The ecology of eelgrass meadows in the Pacific Northwest: a community profile. U.S. Fish Wildl. Serv. OBS 84/24.

Short, F.T. and S. Wyllie-Echeverria. 2000. Natural and human-induced disturbance of seagrasses. *Environmental Conservation* **23**:17-27.

Thom, R.M. 1990. A review of eelgrass (*Zostera marina* L.) transplanting projects in the Pacific Northwest. *Northwest Environmental Journal* **6**:121-137.

Thom, R.M. 1995. Implications for restoration: light, temperature and enriched CO_2 effects on eelgrass (Zostera marina L.). In *Puget Sound Research '95 Proceedings*, Volume 2, January 12-14, Bellevue, Washington. Published by Puget Sound Water Quality Authority, Olympia, Washington, pp. 523-528.

Thom, R.M., and R.G. Albright. 1990. Dynamics of benthic vegetation standing-stock, irradiance, and water properties in central Puget Sound. *Marine Biology* **104**:129-141.

Thom, R.M., L.D. Antrim, A.B. Borde, W.W. Gardiner, D.K. Shreffler, P.G. Farley, J.G. Norris, S. Wyllie Echeverria, and T.P. McKenzie. 1998. "Puget Sound's eelgrass meadows: factors contributing to depth distribution and spatial patchiness." PNWD-4526. Presented at Puget Sound Research '98 Conference, March 12-13, 1998, Seattle Washington. In *Puget Sound Research '98 Proceedings*, pp. 363-370. Published by Puget Sound Water Quality Action Team, Olympia, Washington.

Zimmerman, R.C., J.L. Reguzzoni, S. Wyllie Echeverria, M. Josselyn, and R.S. Alberte. 1991. Assessment of environmental suitability for growth of Zostera marina L. (eelgrass) in San Francisco Bay. *Aquatic Botany* **39**:353-366.